

Challenges and opportunities in accounting for non-energy use CO₂ emissions: an editorial comment

Eric Masanet · Jayant Sathaye

Received: 28 May 2009 / Accepted: 9 June 2009 / Published online: 7 July 2009
© The Author(s) 2009. This article is published with open access at Springerlink.com

1 Introduction

The combustion of fossil fuels for energy purposes is by far the most significant contributor to anthropogenic greenhouse gas (GHG) emissions. However, fossil fuels also contribute to GHG emissions via so-called “non-energy” (i.e., product feedstock) uses by the global chemicals and petroleum refining industries. These emissions, which are often referred to as non-energy use carbon dioxide (NEU-CO₂) emissions, represent a significant and potentially growing source of global GHG emissions.

Simply described, NEU-CO₂ emissions are generated via two primary mechanisms. First, oxidation can occur during production, conversion, use, and treatment processes related to certain chemical and refinery products. Important examples include: oxidation during steam cracking in ethylene production and steam reforming in ammonia production; use phase oxidation of products such as solvents, lubricants, urea fertilizers, and solid carbon for metals manufacture; and oxidation of surfactants and fossil carbon residues during facility wastewater treatment operations.

Second, a fraction of the carbon contained in feedstock fuels can be released via combustion during incineration or energy recovery processes applied to chemical by-products in various chemical plant and refinery operations. Data permitting, NEU-CO₂ emissions arising from energy recovery operations are typically treated as energy-related emissions in national energy balances and GHG emissions inventories (IPPC 2006). In cases where available data are inadequate—for example, when feedstock fuel data are available only on a gross (as opposed to a net) energy basis—all by-product combustion emissions are sometimes treated as NEU-CO₂ emissions (Weiss et al. 2008; Patel et al. 2005).

E. Masanet · J. Sathaye (✉)
Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory,
Berkeley, CA, USA
e-mail: JASathaye@lbl.gov

Recent research suggests that around 30%–40% of the carbon contained in fossil fuels used as product feedstock is released as NEU-CO₂ emissions (see for example Freed et al. 2005). The rest of the carbon remains stored in end use materials such as plastics, synthetic rubber, paints, synthetic fibers, oils, and bitumen. The ultimate GHG emissions implications of this stored carbon depend on the end-of-life disposition path for each material type.

For example, post-consumer plastics might be sent to a landfill (wherein the stored carbon will be effectively sequestered), incinerated for energy recovery (whereby the stored carbon will be released, but some other fuel use may be avoided), or recycled (whereby the carbon remains stored, and additional polymer production—and its associated NEU-CO₂ emissions—might be avoided). The study and quantification of NEU-CO₂ emissions can therefore also provide insight into the magnitude of carbon stored in products in an economy, which can aid in assessing potential future GHG emissions arising from product disposal.

In this issue of *Climatic Change*, Weiss et al. (2009) present the results of a simplified model for estimating global and regional NEU-CO₂ emissions. The authors estimate that in 2000, global non-energy use of fossil fuels was equivalent to around 1,670 million tonnes (Mt) of CO₂ (including carbon storage). To put these emissions into perspective, consider that this quantity was roughly equivalent to the CO₂ emissions attributable to direct fuel use by all of the commercial buildings in the world's developed countries that same year (IPPC 2001; Levine et al. 2007). Of the total amount, the authors estimated that around 700 Mt CO₂ would be released as NEU-CO₂ emissions (i.e., a carbon storage fraction of around 60%), which is an amount nearly as high as the 2000 fuel combustion CO₂ emissions of South America (IEA 2006).

Apart from underscoring the magnitude of global NEU-CO₂ emissions, the Weiss et al. (2009) article leaves the reader with at least two other lasting impressions. First, the estimated source and geographical distributions of global NEU-CO₂ emissions suggest that these emissions are likely to grow significantly in the near term, given global trends in economic growth and projected demand for chemical and refinery products. Second, the article reinforces a common theme among previous NEU-CO₂ studies. Namely, that current data availability and data standardization for estimating NEU-CO₂ emissions are incommensurate with the growing global importance of this GHG emissions category, especially in developing countries (see for example Patel et al. 2005). Both of these points are discussed further below.

2 NEU-CO₂ emissions: a growing problem?

Let's first consider some key trends that suggest that NEU-CO₂ emissions may increase significantly in the coming decades in the absence of targeted mitigation measures. Of particular importance are trends in worldwide production and consumption of fertilizers, polymers, automobiles, and metals.

The Weiss et al. (2009) data suggest that ammonia production is the largest source of NEU-CO₂ emissions (233 Mt CO₂), accounting for around one-third of the global total. Worldwide, the vast majority (around 80%) of all ammonia production is

consumed for agricultural fertilizers (Appl 2009). Weiss et al. (2009) estimate that another 10% (69 Mt CO₂) of global NEU-CO₂ emissions is attributable to the oxidation of urea fertilizers during their use, with over one-half of these use-phase emissions occurring in two rapidly developing countries: China and India.

Another key source of global NEU-CO₂ emissions is steam cracking, which is a process used extensively in the production of polymers. In particular, steam cracking is widely used in the manufacture of commodity polyolefins such as polyethylene and polypropylene, which represent a large share of global polymer production (Zimmermann and Walzl 2009; Whiteley et al. 2009). Weiss et al. (2009) estimate that steam cracking is responsible for around 17% (119 Mt CO₂) of global NEU-CO₂ emissions. Thus, the authors' data suggest that together fertilizers and polymers are likely to be key drivers for around one-half of global NEU-CO₂ emissions.

This finding is noteworthy because worldwide consumption of fertilizers and polymers is expected to grow substantially in the near term. According to a recent soil nutrient depletion study by the United Nation's Food and Agriculture Organization, worldwide fertilizer use is projected to grow at an annual rate of around 1.5% through the year 2030 (Tenkorang and Lowenberg-DeBoer 2008). The sharpest growth is expected to occur in Asia, and in India and China in particular. While improved soil management practices and agricultural technologies may be deployed to reduce future fertilizer demand, in developing economies it is likely to take years for these transitions to occur.

Worldwide consumption of polymers is also poised to grow rapidly. Chemical industry analysts expect that global demand for polymers will increase at an annual rate of over 5% in the next decade, driven in part by economic development in non Annex I economies (Accenture 2008). Particularly strong growth is expected for major polyolefin product categories such as food packaging, fibers and textiles, and injection molded parts. Indeed, there are trends toward reduced use of polymers in such products (e.g., thinner plastic water bottles) and increased polymer recycling in general. However, the steady projected growth in polymer consumption is likely to outweigh such reductions and lead to increased global steam cracking demand in the coming decade. For instance, despite years of market and infrastructure development for polymer recycling in the United States, the overall rate of polymer (and polyolefin) recycling is still less than 10% (U.S. EPA 2008). The most significant growth is expected to occur in China, which in the next decade is projected to emerge as a world leader in both the production and consumption of polymers (Accenture 2008).

Consumption of lubricants for transportation purposes is also likely to grow substantially with increased use of passenger vehicles in developing countries. The increase in passenger vehicle use may indeed be immense; for example, Sperling and Gordon (2009) estimate that the world's fleet of passenger vehicles may double from 1 billion cars to 2 billion cars in the years ahead. Weiss et al. (2009) estimate that oxidation of lubricants accounts for around 5% of global NEU-CO₂ emissions, and that most of these emissions are currently attributable to the Annex I countries. Increased use of cars will likely grow lubricant-related NEU-CO₂ emissions, and shift the balance of these emissions to developing countries. Moreover, increased demand for cars will lead to increased demand for tires, which in turn should increase global demand for synthetic rubber (the components of which are typically produced

via steam cracking) and carbon black (another key source of NEU-CO₂ emissions reported by the authors).

Lastly, the use of solid carbon as a reducing agent or electrode material in metals production (e.g., aluminum and electric arc steel) may also increase in the coming years. Weiss et al. (2009) estimate that around 17% of global NEU-CO₂ emissions is attributable to such solid carbon uses (which also include the production of inorganic chemicals). Although per capita consumption of metals in developed economies has leveled off over time (due in part to product dematerialization and substitution of metals by polymers and composites), significant growth in per capita metals consumption might be expected in developing economies such as China and India as spending on infrastructure, housing, appliances, and cars increases.

Moving forward, whether NEU-CO₂ emissions will increase as a total share of global GHG emissions depends on future growth of other key GHG emissions sources—primarily the combustion of fossil fuels for energy purposes. Regardless, given the above trends it is likely that NEU-CO₂ emissions will grow in absolute fashion, and that developing economies will play a key role in this growth. It follows that this important GHG emissions category warrants increased study, and, more importantly, an increased focus on measures and technologies for mitigating NEU-CO₂ emissions growth.

This latter point raises a key question: If an ultimate goal of GHG emissions tracking is to identify and assess GHG mitigation opportunities, how well do current data sources and reporting mechanisms support this goal with respect to global NEU-CO₂ emissions?

3 Accounting challenges and opportunities

Weiss et al. (2009) present a simplified model (NEAT-SIMP) for estimating country-level NEU-CO₂ emissions. NEAT-SIMP is a derivative of a more comprehensive—and data intensive—model of NEU-CO₂ emissions for developed countries (the so-called NEAT model) (Neelis et al. 2005). The primary impetus for the NEAT-SIMP model was a lack of detailed energy, production, and trade data necessary for estimating NEU-CO₂ emissions for many developing countries. As a result, for such countries the NEAT-SIMP model relies on a number of proxy data and assumptions for estimating NEU-CO₂ emissions, which lead to coarse approximations of these emissions at best.

For example, in NEAT-SIMP feedstock requirements associated with steam cracking and ammonia production are estimated using European data and assumed plant efficiency adjustments for various countries. NEU-CO₂ emissions associated with use of solvents, waxes and paraffins, and wastewater surfactants are estimated via linear regression as a function of gross domestic product. These seem like reasonable approaches considering current data gaps; however, the use of such proxy methods underscores the need for improved data collection and reporting from the major NEU-CO₂ emitting developing countries moving forward.

Even among developed countries, there remain critical data issues that must be resolved to improve the accuracy and comparability of NEU-CO₂ emissions

estimates. These issues have been summarized by previous research related to the NEAT model (e.g., Patel et al. 2005, Neelis et al. 2005; Weiss et al. 2008). Such issues include discontinuities in the way feedstock energy data are reported by various entities (e.g., on a gross basis that includes feedstock energy use or on a net basis that excludes feedstock energy use) and a lack of country-specific carbon storage factors for different end use products. These data issues are pervasive given the complexity and interconnected nature of chemical plant and refinery processes. Exacerbating the problem is a general lack of data on facility-level energy and feedstock flows that would help improve the partitioning and reporting of feedstock carbon estimates into oxidized, combusted, and stored fractions.

It follows that, in practice, NEU-CO₂ emissions estimates must often be synthesized in a fairly ad hoc fashion even in data-rich developed countries. In this process it is often necessary to assemble information from a diversity of sources, which may have been issued in different years, and whose original purpose may have been unrelated to NEU-CO₂ emissions accounting. Such information sources typically include production statistics from trade journals and industry associations, energy and trade data from national and international statistics bureaus, air and water emissions data from regulatory control agencies, public and private emissions models, and estimates from academic journals and reports. For instance, a recent inventory of U.S. NEU-CO₂ emissions relied on data inputs from at least 20 different sources of the aforementioned types (Freed et al. 2005). In light of prevailing NEU-CO₂ emissions data gaps and compatibility issues, this reliance on disparate data sources is likely to introduce significant uncertainties into final NEU-CO₂ emissions estimates. A move toward coordinated and standardized reporting to central data repositories would vastly improve fundamental data compatibility and the accuracy of NEU-CO₂ emissions estimates (Patel et al. 2005).

Despite these pervasive data challenges, work to date has made considerable strides toward bringing the previously fuzzy picture of global NEU-CO₂ emissions into sharper focus. This work has allowed for identification of likely “hot spots” of current and future NEU-CO₂ emissions in different countries, which is a critical first step toward more thorough analyses of NEU-CO₂ emissions mitigation options. Clearly, a number of important mitigation options are already available. Organic fertilizers, improved soil management, and the use of nutrient catch crops might reduce ammonia demand and fertilizer use (see for example Rode et al. 2009). Dematerialization, materials substitutions, and higher materials recycling rates might reduce demand for NEU-CO₂ emitting production processes. Improved energy recovery processes (including elimination of flaring) might lead to reduced facility-level demand for other GHG-emitting fuels.

However, the thorny business of evaluating such discrete GHG mitigation options in specific countries—including their investment costs and GHG emissions reduction benefits as compared to competing options—will require greater NEU-CO₂ emissions data accuracy and compatibility across industries and regions. Such data aspects are critical for reliable NEU-CO₂ emissions baselines, which are the foundation of robust and policy-relevant GHG mitigation analyses.

The inadequacy of current NEU-CO₂ emissions data with respect to GHG mitigation analysis becomes apparent when one considers the state of data for global GHG emissions sources of (potentially) similar magnitude. Let’s use the case of commercial

buildings in developed countries as an illustrative benchmark.¹ In general, data on commercial building fuel use, end use equipment, technology penetrations, and energy-related GHG mitigation measures are quite rich in developed countries. Examples of such data sources in the United States include the national Commercial Building Energy Consumption Survey (U.S. DOE 2008), California's Commercial End Use Survey (Itron 2006), and the DEER building technology database (CPUC 2008). As a result of such data availability, the barriers, costs, and GHG emissions reduction potential of commercial building mitigation options in these countries have been well studied (see for example Brown et al. 2008). Such information is critical to policy makers in their decisions regarding which mitigation options to promote and financially support. In comparison, existing data for characterizing NEU-CO₂ emissions seem markedly incommensurate with their global magnitude, growth potential, and importance as a GHG mitigation opportunity.

It is probably not realistic to expect the same level of data detail for NEU-CO₂ emissions as we enjoy for commercial buildings, given the proprietary nature of chemical plant and refinery operations. However, the (albeit simplistic) comparison to commercial buildings illustrates the considerable knowledge gaps we face when assessing NEU-CO₂ emissions mitigation options using current data. Recent bottom-up modeling work in the United States (Freed et al. 2005) and the NEAT model in Europe (Neelis et al. 2005) might be sufficient for preliminary cost–benefit analyses of discrete NEU-CO₂ emissions mitigation options in those regions. However, for developing countries where future NEU-CO₂ emissions mitigation is likely to be even more important, current data are inadequate for the task. Until these data are improved, the prevailing knowledge gaps could present a significant barrier to the development, deployment, and transfer of NEU-CO₂ mitigation measures.

4 Carbon storage and end-of-life fate

So how well do existing GHG and NEU-CO₂ emissions inventory methods account for the remaining 60%–70% of feedstock carbon that is stored in products? For products that are disposed of via landfill (e.g., post-consumer polymers) or continuously used/recycled (e.g., bitumen in asphalt pavements), stored carbon is assumed to be sequestered indefinitely (and therefore not a near-term source of CO₂ emissions). For products that are ultimately combusted via incineration or energy recovery processes (e.g., polymers and oils), existing national GHG inventory methods should account for the resulting CO₂ emissions as waste- or energy-related emissions (IPPC 2006). This latter emissions category should also account for used oils that are reprocessed into and subsequently combusted as fuels, such as marine bunker fuel (see for example Boughton and Horvath 2004). It follows that, in theory, all feedstock carbon releases should be accounted for using existing GHG and NEU-CO₂ emissions inventory protocols.

In reality, however, it is possible that some carbon stored in products is released via uncontrolled incineration and is therefore not captured in current national GHG

¹Recall that GHG emissions from direct energy use by commercial buildings in developed countries in 2000 were roughly equivalent to the 2000 global NEU-CO₂ feedstock equivalent (emissions plus carbon storage) estimated by Weiss et al. (2009).

emissions inventories. Such incineration might occur for post-consumer waste that is generated domestically. Incineration might also be used to recover materials from imported waste products in the informal recycling sector, particularly in developing countries. One example is the combustion of polymers contained in circuit boards, wires, and housings in informal e-waste recycling operations (Scanlon 2004). Because such uncontrolled emissions are unreported, their magnitude is unknown. A first step toward better understanding these emissions would be to improve and harmonize country-level data on the consumption, lifetime, end-of-life disposition path (landfill, recycling, etc.), and waste import/export flows relevant to key products (e.g., plastics, tires, oils, and appliances). Data of this type would clearly require cooperation and regular, standardized reporting from producers, sellers, importers and exporters, and waste agencies. However, such data would be invaluable toward preliminary mass flow studies that could identify key “hot spots” of uncontrolled end-of-life emissions for additional study.

An added benefit is that such mass flow data could be used to improve life-cycle assessment (LCA) evaluations of NEU-CO₂ emissions mitigation options. Consider the case of polymers, whose total life-cycle environmental “footprint” can vary considerably depending on whether they are recycled, incinerated, or sent to a landfill at their end-of-life stage (see for example Masanet and Horvath 2007). Improved mass flow data that better reflect actual end-of-life fate would clearly lead to more accurate and region-specific LCA “footprints” for polymers. Further consider that a possible mitigation option is to replace metals by polymers as a so-called light-weighting strategy in applications such as automobiles and product packaging. In this case, the use of polymers might lead to GHG reductions in transportation fuel-related GHG emissions while also reducing NEU-CO₂ emissions related to metals production. However, the increased polymer demand might also increase steam cracking demand, thereby raising NEU-CO₂ emissions from that important source. To determine whether this potential mitigation option minimizes GHG emissions (and other environmental impacts) at the societal level, an LCA approach is advisable. With improved mass flow data, the robustness of this LCA “footprint” dependent-policy decision would be improved significantly.

Moreover, improved mass flow data for carbon-storing products would allow for better analysis of the GHG emissions implications of regional waste management options. For instance, such data would improve analyses of how improved polymer recycling might lead to reduced steam cracking NEU-CO₂ emissions, and other GHG emissions savings, by offsetting the production of virgin polymers. Other analyses that would benefit include assessments of how improved energy recovery from waste flows of polymers and tires might lead to net GHG emissions reductions by offsetting fuels such as coal, petroleum coke, or oils in cement kilns or smelters.

5 Conclusions

Given likely trends in global economic development and demand for products from the chemicals and refining industries, it seems probable that global NEU-CO₂ emissions will increase in the near term in the absence of targeted mitigation measures. As discussed in this article, much work remains to improve global and regional characterizations of NEU-CO₂ emissions. In particular, data gaps and

incompatibility issues must be addressed to facilitate more robust analyses of the costs and benefits of various NEU-CO₂ emissions mitigation options, especially at the regional level.

However, there is also cause for optimism. Data sources and models developed to date, including NEAT and NEAT-SIMP, are steadily improving our understanding of the source and geographical distributions of NEU-CO₂ emissions. Moreover, the application of these models is shining a bright light on the pervasive data issues that cloud our understanding of NEU-CO₂ emissions, especially with respect to developing countries. As such, the body of work to date has served the dual purpose of improving our knowledge of this important GHG emissions category while building a case for addressing data barriers in an internationally-coordinated fashion (see for example Patel et al. 2005).

A promising development in the United States is the U.S. Environmental Protection Agency's recent proposal for mandatory GHG emissions reporting from industrial facilities that emit more than 25,000 tonnes of CO₂ per year (Federal Register 2009). The proposed rules would affect around 13,000 plants in the United States, including the nation's petroleum refineries and chemicals plants. Specific data collection and reporting guidelines are offered for key NEU-CO₂ emitting industries (e.g., ammonia, petrochemicals, and aluminum) that will provide greater data detail and accuracy with respect to NEU-CO₂ emissions than current disparate data sources provide. Proposed reporting guidelines include sampling of carbon content for feedstocks, reporting of CO₂ emissions from anode consumption, the use of continuous emissions monitors for reporting of NEU-CO₂ emissions from major processes, conducting process mass balances, and other requirements that address some key bottom-up data gaps exposed by previous researchers. If successful, the proposed data collection approaches might serve as a model to replicate elsewhere in the world, which could improve global NEU-CO₂ emissions models and inventories considerably.

Open Access This article is distributed under the terms of the Creative Commons Attribution Noncommercial License which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

References

- Accenture (2008) Trends in manufacturing polymers: achieving high performance in a multi-polar world. <http://www.accenture.com/>
- Appl M (2009) Ammonia. Ullmann's encyclopedia of industrial chemistry, 7th edn. Wiley, Hoboken
- Boughton B, Horvath A (2004) Environmental assessment of used oil management methods. *Environ Sci Technol* 38(2):353–358
- Brown R, Borgeson S, Koomey J, Biermayer P (2008) U.S. building-sector energy efficiency potential. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-1096E
- California Public Utilities Commission (CPUC) (2008) Database for energy efficient resources. Available at: <http://www.deeresources.com/>
- Federal Register (2009) Proposed mandatory greenhouse gas reporting rule. 74(68):16609–16726. http://www.lexisnexis.com/help/CU/How_to_Cite/Federal_Register.htm
- Freed R, Mintz C, Lanza R, Hockstad L (2005) Analytic framework for analyzing non-energy uses of fossil fuels as petrochemical feedstocks in the USA. *Resour Conserv Recycl* 45(3):275–294
- Intergovernmental Panel on Climate Change (IPCC) (2001) Climate change 2001: mitigation. Contribution of working group III to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

- Intergovernmental Panel on Climate Change (IPPC) (2006) 2006 IPCC guidelines for national greenhouse gas inventories, prepared by the national greenhouse gas inventories programme. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). Published: IGES, Japan
- International Energy Agency (IEA) (2006) CO₂ emissions from fuel combustion, 2006 edn. Paris, France
- Itron (2006) California commercial end use survey. California Energy Commission, Sacramento, California. CEC-400-2006-005
- Levine M, Ürge-Vorsatz D, Blok K, Geng L, Harvey D, Lang S, Levermore G, Mongameli Mehlwana A, Mirasgedis S, Novikova A, Rilling J, Yoshino H (2007) Residential and commercial buildings. In: Climate Change 2007: Mitigation. Contribution of working group iii to the fourth assessment report of the intergovernmental panel on climate Change. Cambridge University Press, Cambridge
- Masanet E, Horvath A (2007) Assessing the benefits of design for recycling for plastics in electronics: a case study of computer enclosures. *Mater Des* 28:1801–1811
- Neelis ML, Patel M, Gielen DJ, Blok K (2005) Modelling CO₂ emissions from non-energy use with the non-energy use emission accounting tables (NEAT) model. *Resour Conserv Recycl* 45(3):226–250
- Patel M, Neelis M, Gielen D, Olivier J, Simmons T, Theunis J (2005) Carbon dioxide emissions from non-energy use of fossil fuels: summary of key issues and conclusions from the country analyses. *Resour Conserv Recycl* 45(3):195–209
- Rode M, Thiel E, Franko U, Wenk G, Hesser F (2009) Impact of selected agricultural management options on the reduction of nitrogen loads in three representative meso scale catchments in Central Germany. *Sci Total Environ* 407(11):3459–3472
- Scanlon K (2004) Poison PCs and toxic TVs: California's biggest environmental crisis That you've never heard of. Report by Silicon Valley Toxics Coalition, Californians against waste, and materials for the future. <http://www.etoxics.org/>
- Sperling D, Gordon D (2009) Two billion cars: driving toward sustainability. Oxford University Press, New York
- Tenkorang F, Lowenberg-DeBoer J (2008) Forecasting long-term global fertilizer demand. Food and Agriculture Organization, United Nations, Rome, Italy
- United States Department of Energy (DOE) (2008) 2003 Commercial building energy consumption survey. Energy Information Administration, Washington, DC
- United States Environmental Protection Agency (EPA) (2008) Municipal solid waste in the United States: 2007 facts and figures. Office of Solid Waste, Washington, D.C. EPA530-R-08-010
- Weiss M, Neelis ML, Zuidberg MC, Patel MK (2008) Applying bottom-up analysis to identify the system boundaries of non-energy use data in international energy statistics. *Energy* 33(11):1609–1622
- Weiss M, Neelis M, Blok K, Patel M (2009) Non-energy use of fossil fuels and resulting carbon dioxide emissions: *bottom-up* estimates for the world as a whole and for major developing countries. *Clim Change* doi:10.1007/s10584-009-9562-x
- Whiteley et al. (2009) Polyolefins. Ullmann's encyclopedia of industrial chemistry, 7th edn. Wiley, Hoboken
- Zimmermann H, Walzl R (2009) Ethylene. Ullmann's encyclopedia of industrial chemistry, 7th edn. Wiley, Hoboken